APPLIED TECHNOLOGY CAPABILITIES & INTEREST AREAS

IARPA SCISRS PROGRAM
27 AUG 2020

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1 Executive Summary

Applied Technology (AT), a prototyping center within Motorola Solutions, Inc. (MSI), creates proof-of-concept and low-volume specialty communications products that excel in small Size, Weight, and Power (SWaP) form factors. With respect to Machine Learning (ML), AT is applying ML in situations that can enhance performance for embedded applications on low SWaP devices. While training may be employed on larger computing equipment, the inference computation is performed on embedded hardware. AT's nascent work in ML includes enhancements in RF signal classification, improvements to Angle of Arrival estimation in beamforming applications, and exploration in audio and video triage. AT has demonstrated competency in ML applications by placing in the Army RCO Signal Classification Challenge.

2 Applied Technology Overview

On any given day, every moment matters to someone, somewhere. And every moment, Motorola Solutions' innovations, products and services play essential roles in people's lives. We help firefighters see around buildings and police officers see around street corners. We keep utility workers connected and visible to each other with real-time voice and data communication across the smart grid. We provide the situational awareness first responders need when a moment brings catastrophe. We help people be their best in their moments that matter.

Applied Technology (AT) is a prototyping center within Motorola Solutions, Inc. (MSI). We create proof-of-concept and low-volume specialty products in small Size, Weight, and Power (SWaP) form factors for government and private industry, primarily focused on both custom and commercial wireless communications standards, including GSM, CDMA2K, W-CDMA, WiFi, WiMAX, and LTE.

Applied Technology has a long history of designing custom hardware and software to meet specific government customer needs. We have applied machine learning to our product lines at the edge to provide improved performance for embedded application environments. The following sections describe our applicable Independent Research and Development (IR&D) efforts.

In the mid 2000s, AT started developing Software Defined Radio (SDR) platforms based on a proprietary MSI Radio Frequency Integrated Circuit (RFIC). By the fourth generation, ten years later, MSI SDR platforms moved to using a commercial RFIC from Analog Devices. The current SDR platforms have an operating frequency of 70 MHz to 6 GHz with up to 56 MHz of instantaneous RF bandwidth. The mid-tier model provides 8 half-duplex transceivers, is 6.3" by 3.0" by 1.2", and weighs just 1 pound. In 2018, design efforts started for the sixth generation SDR, which will again be based on a proprietary MSI/AT RFIC to achieve performance and capabilities not possible with commercial parts. The new RFIC, now available, supports 1 GHz instantaneous bandwidth (IBW) and frequencies from near DC to 27 GHz with a roadmap to achieve frequencies up to 66 GHz.

In addition to SDR platform development, AT develops custom Radio Applications for a variety of passive and active missions, including: RF recording and playback, spectrum survey and signal characterization, direction finding and geolocation, secure communications, Signal Intelligence (SIGINT), Electronic Warfare (EW), and communications network monitoring. Most, if not all, of these missions have aspects that can be enhanced and optimized with Artificial Intelligence (AI) and Machine Learning (ML) algorithms.

3 Machine Learning for RF Signal Classification

AT has invested in AI/ML enhancements for a cellular survey mission as a way to significantly accelerate system performance. Cellular survey involves detecting the cellular base station frequencies in an environment and decoding the cellular network's broadcast control channel information.

Traditionally, scanning RF spectrum to find these cellular signals of interest was fairly straightforward – tune to each potential channel, attempt to synchronize and decode the downlink control channel, and move on. This brute-force search approach was effective because of the relatively small number of channels used by 2G and 3G systems. However, 4G systems have many more bands and candidate channels (1000s vs. 100s), so the brute-force survey time became quite long without using additional SDR hardware. The need for a faster, more efficient signal detection and identification algorithm motivated AT's initial foray into RF AI/ML.

In June of 2016, AT initiated an IR&D proof-of-concept system that used machine learning to accelerate UMTS survey. For this project, the system swept the UMTS frequency bands and calculated the Power Spectral Density (PSD). A Deep Learning model was trained to identify the unique UMTS PSD spectral signature and thus to identify frequencies (i.e., channels) that were highly likely to contain UMTS signals. This output was then fed into our existing survey tool to prioritize those channels and accelerate the overall survey time. The proof of concept system was embodied as adjunct hardware and software running on a laptop computer. The Deep Convolutional Neural Network (CNN) exhibited greater than 95% accuracy with ~3% misses and ~2% false positives.

In 2017, AT launched a follow-on AI/ML project. The primary goal was to extend the AI/ML accelerated survey capability to include the three remaining cellular waveforms so that all cellular survey missions were accelerated – UMTS, GSM, LTE, and CDMA2K. The increased scope required additional RF data for training and verification across a range of waveforms and representative environments. The AT RF Record and Playback Radio Application together with an NEN3000-VIPER SDR was used to record four 40 MHz sections of spectrum (i.e., 160 MHz at a time) to an SSD as raw I/Q samples. Through repeated lab playback and file-based processing the team exhaustively labeled each cellular waveform with millisecond level accuracy. The labeled dataset was then used to design and train CNN models to identify candidate frequencies for UMTS, GSM, LTE, and CDMA2K waveforms.

Figure 1: 2017 Cellular Survey IR&D Hardware

An embedded-class Graphics Processing Unit (GPU), specifically the NVIDIA Jetson TX2 (shown in Figure 1), was used for inference acceleration. The procured TX2 was housed in a semi-rugged enclosure to continue the adjunct hardware/software approach. An engineering user interface from this system (shown in Figure 2) displays both the raw RF data and center frequency predictions from each trained model. The final system is capable of analyzing 100 MHz for all cellular waveforms in 4 seconds, which, when combined with the waveform-specific decoder Radio Applications, leads to a 10x improvement in the cellular survey mission performance. Further performance improvements are available to increase the AI/ML accelerated signal detection to 1 GHz/s using the same hardware configuration. AT launched a commercial AI Survey (AIS) product based on this Intellectual Property (IP) in 2018.

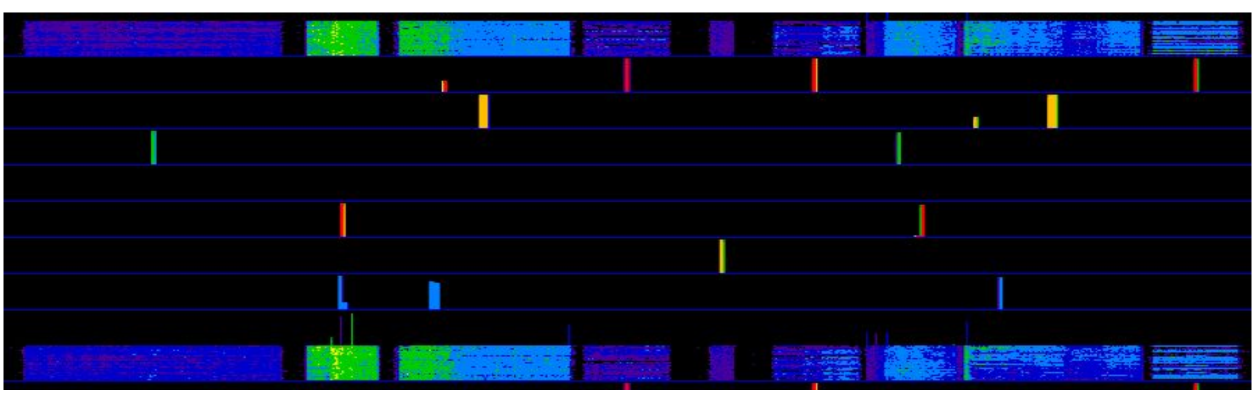

Figure 2: Engineering UI with AI/ML Model Output over 70 MHz

In 2018, AT began another variation of the RF Machine Learning effort, specifically, identification of DMR signals. This poses two distinct and significant challenges as compared to previous efforts. First, DMR signals are much narrower bandwidth than cellular base station waveforms: < 15 kHz vs. 1-20 MHz. This forced finer resolution data representations to identify the waveform of interest. Second, DMR waveforms are intermittent as opposed to cellular base station (downlink) waveforms that are continuous. A further requirement for this effort was the need to create a data set for DMR waveforms – capture waveforms and label them – to use for training and verification. This project also used deep convolutional network models and concluded with a substantial improvement over the incumbent algorithm; the DL-based classifier has greater sensitivity with lower false positive rates than the incumbent technique. Moreover, the DL-based classifier is able to successfully differentiate between DMR and P25 signals, which have very similar spectral signatures and consistently fooled traditional classifiers.

In 2018, AT also participated in the Army Rapid Capabilities Office (RCO) Signal Classification Challenge (ASCC). The Challenge drew wide interest from industry, government, and academia with 160+ registered teams and individuals from FVEY countries; 49 of these participants actively participated in the 90 day competition. The Challenge required participants to identify 24 different waveforms (digital modulation, analog modulation, and noise) from short, baseband RF data vectors at a variety of Signal-to-Noise (SNR) levels. The AT team, THUNDERINGPANDA, was awarded the 3rd place prize in the competition and is currently engaged with the RCO, which is now the Rapid Capabilities and Critical Technologies Office (RCCTO), exploring follow-on RF ML opportunities to address operational needs.

AT's success in the ASCC was built on expertise in both RF signal processing and the latest Deep Learning algorithms and model architectures. During the competition the team developed novel approaches to data augmentation, RF filtering, and ensemble networks, all of which were essential to success. AT is now pursuing two patents related to the team's innovations in applied Deep Learning algorithms.

4 Machine Learning for RF AoA & Geolocation

Traditional approaches to RF Angle of Arrival (AoA) estimation and geo-location are often subject to a complex set of perturbations from both installation and antenna variations. In 2017, AT employed Machine learning to aid in AoA estimation, and to assess its applicability and potential for AoA improvement beyond traditional approaches. A Random Forest Regression model was created from AoA data which had already been processed with traditional manifold-based methods. Clear improvement was achieved on the selected field data with this approach, in that the RMS AoA error using the traditional approach was 2.18°, while the error decreased to 1.31° with the machine learning approach. In addition to the accuracy improvement, available flight time was increased due to the reduction in calibration time.

5 Machine Learning for Video

AT has designed video capture products with time and movement triggers. We envision AI/ML as a means to add object, face, and person detection even in the presence of occlusions. This is an active area of IR&D research in 2019. In addition, MSI recently acquired Avigilon, a company that designs, develops, and manufactures video analytics, network video management software and hardware, surveillance cameras, and access control solutions. Being part of the same company affords us the opportunity to collaborate with them to adapt their products and technology for our customers' use.

6 Statement Regarding Classified R&D

Applied Technology facilities include accredited SCIF workspace and conference rooms. AT also has the requisite cleared personnel to conduct research and development at the TS//SCI level.

7 Citations

The nature of AT's government contracts limits public domain citation opportunities. However, the following are recent citations applicable to AT's ML efforts.

- **US Army Signal Classification Challenge**

  Competition Website: https://sites.mitre.org/armychallenge/

  Army Press Release:
  https://www.army.mil/article/210391/army_contest_invites_winning_innovators_to_bring_ai_capabilities_to_soldiers

- **55th Association of Old Crows International Symposium & Convention, Nov-2018 Advancing Automation for EMS Warfighting Technical Session**

  Advances in RF Signal Detection and Classification via Deep Learning
  Mr. Stephen Govea - Presenter
  https://www.crows.org/mpage/SpeakerGovea
  https://www.crows.org/mpage/SymposiumAgenda